LORD KELVIN

PHYSICIST MATHEMATICIAN ENGINEER

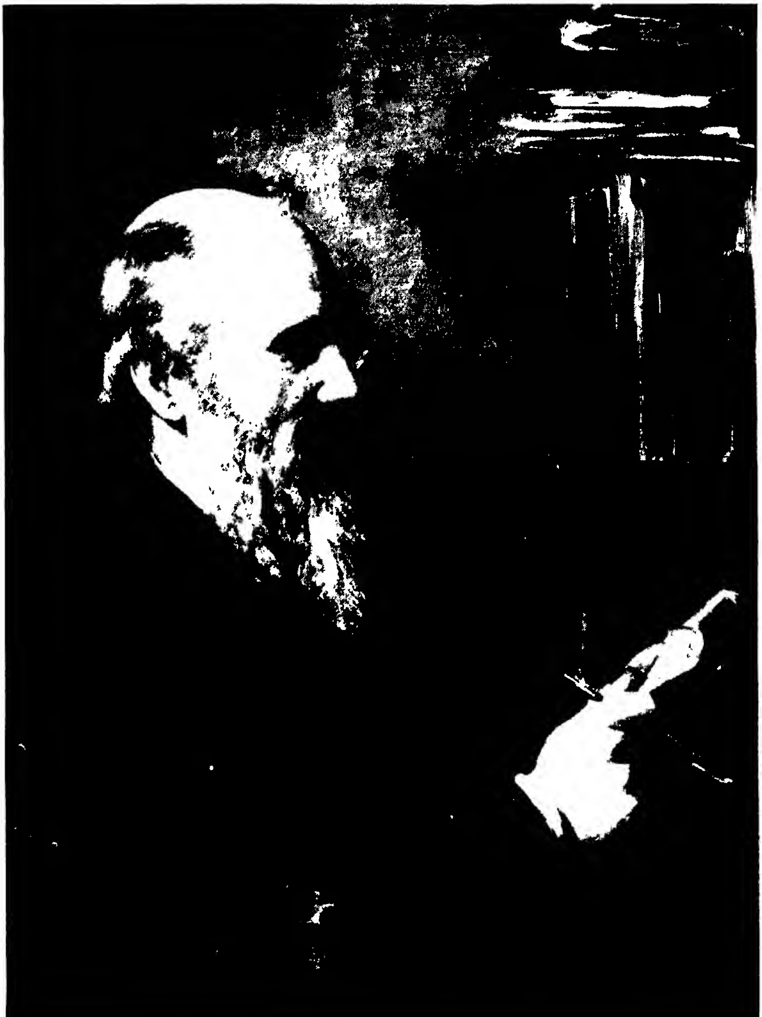
A. P. YOUNG

LORD KELVIN

William Thomson—who was born in 1824, became Lord Kelvin in 1892, and died in 1907—was one of the most distinguished physicists of all time. In the course of a long and laborious career he made many great contributions to the sciences of thermodynamics, electricity and navigation; in this short study of his work emphasis is laid upon his possibly unique combination of mathematical and engineering genius, with its profound effect upon the development of applied science.

The author, A. P. Young, an Officer of the Order of the British Empire and a Member of the Institution of Electrical Engineers, was formerly Manager of the Rugby works of the British Thomson-Houston Company, Ltd., and a Visiting Fellow of Nuffield College, Oxford (1939–47). He is a member of the Factory Welfare Advisory Board of the Ministry of Labour and National Service, and Chairman of both the Confederation of Management Associations and the Institution of Works Managers.

Science in Britain



Lord Kelvin in his study

(From a portrait painted in 1886–1887 by Elizabeth Thomson King: now in the National Portrait Gallery, London)

LORD KELVIN

BY

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Author of

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CONTENTS

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The picture of the Quadrangle of the Old Glasgow College is reproduced by courtesy of Messrs. Macmillan & Co. Ltd., and the picture of Lord Kelvin with his sister Mrs. King by courtesy of Messrs. Hodder & Stoughton, Ltd. The illustrations of apparatus appear by courtesy of Messrs. Kelvin, Bottomley and Baird, Ltd.

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INTRODUCTION

The scientific age, characterised by experimentation, observation, analysis and deduction, really started with Roger Bacon in the thirteenth century; but not until the advent of Watt's steam engine, less than two hundred years ago, did applied science become a potent force ministering to the needs of mankind. The march of knowledge in the nineteenth century has now become a headlong charge into the illimitable depths of atomic structure; new sources of energy are rapidly unleashed to serve our purposes for good or evil.

While the recent tempo of scientific advancement has brought the human family face to face with the great moral issue of so organising its affairs that this expanding knowledge will be used only to serve the highest purposes enshrined in the human spirit, we must not—as some may be tempted to do—condemn the earnest endeavours of those who, frequently in the pursuit of pure knowledge, have effected that advancement. The moral issue has always been there, at every stage of man's onward march; but now, for the first time, evasion of it is seen to involve the end of mankind.

Under that awe-inspiring threat the peoples of a world reduced to small compass by the spectacular evolution of scientific intelligence are being forced to learn the art of co-operative endeavour. Of course, this world problem—which the United Nations Organisation is tackling so hopefully—abounds with difficulties; only by the continual overcoming of obstacles and impediments can the mind and spirit of man advance in a healthy and Godlike way. Recognising this necessity, we can surmount our current problems and move forward to higher and nobler reaches of living and service.

Britain has made an outstanding contribution to the progress of pure and applied science. This island gave to the world the industrial revolution, from which has been developed the mechanised industrial structure of our middle twentieth-century civilisation. The dominant power of industry can be used for the dispensation of economic and social justice to all peoples; speedy establishment of such justice could become the most potent influence for world peace, for it would imply democratic govern-

ment (or management), and recognition by all types of working groups in all plans, programmes and policies, of the supreme worth of human personality.

To-day we see Britain advancing steadfastly towards a true form of industrial democracy. Our rate of progress will be profoundly influenced by our success in perfecting the instrument of education, and in applying it wisely and purposefully throughout the life-span of the individual. A revolution in educational method and technique is implicit in the new Education Bill, passed in the throes of total war; and an impartial observer of new educational trends in Britain might with good reason conclude that the British people are on the threshold of their greatest period. Out of suffering and tribulation, with hard work, tolerance, faith in the eternal good in humanity, they may create a new and happier economic and social pattern that the world, before very long, will gladly copy.

Britain may be said to have become a vast research station in which scientific, educational, social, religious and political problems are under investigation in the common interest. National teamwork is here shown at its best; and the working teams build on foundations laid by those who have gone before—great teachers, thinkers, governors, scientific investigators, craftsmen, engineers and industrial leaders.

William Thomson, who became Lord Kelvin, was one of these layers of foundations in the second half of last century. He was the great protagonist of applied science, and by precept and example he proclaimed that unity of purpose between education and industry which must receive full recognition if economic and social justice is to prevail. He was perhaps unique in his combination of a first-rate mathematical mind with a rare quality of engineering instinct. His contribution to the science of thermodynamics was masterly and outstanding; the science of navigation had a peculiar attraction for him, and his many inventions still minister to our needs; and the science of electricity owes much to his theoretical and practical work.

To that work he brought unceasing and at times startling mental and physical energy; he was also a teacher possessed of remarkable spiritual power, and a kindly and humble man, full of love for all created things.

FAMILY AND HOME LIFE

In Britain the scientific advances of the nineteenth century were largely isolated from the life of the common people; not until the present century did they begin to affect the comfort and convenience of the community at large. Those advances were made by giants, notably Sir Humphry Davy, Michael Faraday, James Clerk Maxwell and Sir J. J. Thomson. The work of these pioneers was done largely within Lord Kelvin's long life-span; his own rare combination of talents has secured his name its place among the names of his great contemporaries.

Faraday, aged thirty-three, was completing in the Royal Institution, London, a magnificent and little-known piece of research work in the alloying of iron with different metals—and thus opening the way for the manufacture of those alloy steels which are now the necessary ingredients of the refined mechanisms that serve our daily needs—at the time when the subject of this essay was born.

The actual date was June 26, 1824. William Thomson was fortunate in having forebears rich in character and personality; his father, James Thomson, was a remarkable man, who profoundly influenced the character, outlook, and work of his most famous son. The spiritual bond between the pair was beautiful and strong, and remained a force throughout William Thomson's life.

James Thomson quite early perceived exceptional potentialities in his fourth child, and there was conscious planning in his parental instruction and guidance. A brief study of the family atmosphere is therefore necessary.

James Thomson was born in 1786 on a farm called Annaghmore, near Ballynahinch, County Down, Ulster (Northern Ireland). He was the youngest of five children. The family had moved to Ulster from Ayrshire, Scotland, during the seventeenth century, settling in a farm that remained in the family until the Irish famine of 1847. During

the Irish rebellion of 1798 the twelve-year-old boy James helped his sisters secretly to carry food to the insurgents before the Battle of Ballynahinch.

As a youth, James Thomson studied at Glasgow College, and was an exemplary and successful student. He gained his degree of Master of Arts and became mathematics master in Belfast College and its preparatory schools. At that time, early in the nineteenth century, power-driven machines were beginning to shape the industrial revolution. Walking one afternoon by the banks of the Clyde, the student James Thomson was startled to see for the first time a funnelled boat gliding on the waters. It was the *Comet*—one of the earliest steamboats, driven by a four-horse-power engine, and costing in all £192. In after years James Thomson must often have recounted this memorable experience; no doubt the story made a deep impression on his son William, whose life's work was to be accomplished in Glasgow University, near the scene of the incident.

But in his parents William Thomson was twice blessed; his mother, Margaret Gardner, was a woman of supremely fine character. Her father, a Glasgow citizen of considerable means, had fought as a volunteer in the American War of Independence; on one occasion his life was saved by a large and strong silver watch which prevented a bullet from penetrating his body. Margaret Gardner's mother died at an early age, bequeathing to Margaret, then only seventeen years old, the duties of caring for four other children. When visiting relations in Belfast Margaret met James Thomson for the first time at a dinner-party. They became engaged on the way home. Their marriage took place in 1817, when Margaret was twenty-seven.

It was a happy union, and there were seven children, of whom the first four were Elizabeth, Anna, James and William. William was a bonny child, and was not wholly unconscious of the fact; it is recorded that when only two years old he was discovered sitting in front of a looking-glass, smiling at himself and saying: 'P'itty b'ue eyes Willie Thomson got!' The beloved mother died in 1830, when William was only six; and until Elizabeth grew to womanhood the responsibility for running the household was taken over by their aunt, Agnes Gardner, and by Nurse Sally, a firm disciplinarian with a very orderly mind.

William Thomson thus belonged to that large group of distinguished

people deprived at an early age of a mother's love and influence. But he was more fortunate than many; James Thomson, stunned by the loss of his wife, sought recovery in spending on his children a wealth of parental love. William became his special pet 'partly on account of his extreme beauty (manifest in all his pictures in later life), partly on account of his wonderful quickness of apprehension, but most of all, I think, on account of his coaxing, fascinating ways, and the caresses he lavished on his "darling Papa" '.

When William was six and a half he was sent to attend classes in the Glasgow Institute for an hour or two each day. James Thomson devoted himself assiduously to the education of his children; one of his methods was to encourage discussion among them during a regular morning walk. In the evening, after an early dinner, he gave lessons and readings to the family group. In 1831, when only seven years old, William earned his first prize. That was the momentous year when Faraday gave to the world the principle of electromagnetic induction, the foundation-stone of the electric age.

In the winter of 1831 James Thomson was appointed Professor of Mathematics in Glasgow University. The family had a hard struggle in their new abode; but William's studies were continued by attending, with his elder brother James, the Junior Mathematics Class. William's precocity is revealed in a letter which he received, more than fifty years later, from one of his old schoolmates, who wrote: 'As a mere child you startled the whole class, not one of whom could answer a certain question, by calling out: "Do, papa, let me answer." The impression in my mind has never been effaced.'

The family's first summer in Scotland was spent at Rothesay. There James Thomson devoted himself indefatigably to the education of his children; the elder four spent some hours with him in his study each morning. Their father enjoyed reading aloud to them; he was conscious of the supreme importance of a liberal education, and the readings included Pope's translations of the *Iliad* and *Odyssey*, several plays of Shakespeare, Goldsmith and Sheridan, and selections from the poets. The eldest sister, Elizabeth, has recorded how William's strong sense of humour often set the group laughing.

At this time William and James also attended Dr. Cooper's Natural History Class, and used the opportunity to pass on the instruction received to their sisters in the evening, James concentrating on Elizabeth, and William on Anna. William thus gained his first experience as a teacher. The intense and unceasing activity of his mind was now beginning to reveal itself. After going to bed one evening, he astonished the household by crying: 'Eureka! Eureka!' His father rushed to the room and found him standing barefooted in his nightgown on the landing, excited and triumphant. He had solved a problem which had engaged his mind since he left the classroom, and had scribbled the solution on a slate by his bedside. He was then only eight years old, but here we see the genesis of a lifelong practice—the recording of ideas and observations in the famous green notebooks, one of which always accompanied him. A series of over a hundred of these notebooks has been preserved.

When he was ten years old William and his brother James became regular students at the University. He matriculated on November 14, 1834; this exceptional achievement gives point to his view, expressed a few months before his death, that 'a boy should have learned by the age of twelve to write his own language with accuracy and some elegance; he should have a reading knowledge of French, should be able to translate Latin and easy Greek authors, and should have some acquaintance with German. Having learned thus the meaning of words, a boy should study logic'. This declaration, described by Sir J. J. Thomson as 'the most optimistic scheme of juvenile education ever put forward', illuminates the exceptional mental equipment of the boy William Thomson.

When he was twelve, William, again with his brother James, was attending the class in Natural Philosophy and became interested in the study of electricity. Their father encouraged them to combine book-learning with hand work—a combination often neglected, without which it is hardly possible to maintain a balanced and healthy growth of human personality. The boys were provided with a room in which they could do mechanical work and pursue philosophical research. They constructed frictional electrical machines, Voltaic piles, and galvanic batteries,

drawing on the lumber-room for much of their material. It is recorded that 'the brothers contrived, and themselves made, most, if not all, the apparatus they used in their experiments; and thus their inventive faculties were quickened, and originality was promoted'.

Experiments were conducted with metals and fluids, with light, heat magnetism and electricity. The polarisation of light engaged William's attention, and he eagerly pursued experiments in this field of inquiry. This crude experimental research laboratory may be described as the harbour from which William Thomson embarked on his voyage of scientific discovery.

Meanwhile his University studies made rapid progress; he habitually obtained first prize for the year's work, with James second, much to the joy of their family. There was no jealousy between the brothers; their mutual respect and helpfulness bore witness to their father's spiritual influence.

When William was fifteen years old the family visited London. It was a great educational experience for him. St. Paul's Cathedral, the newspaper offices in Fleet Street, Madame Tussaud's Waxworks, Hampton Court Palace, the British Museum and Westminster Abbey (where he was finally to rest) were included in the itinerary, together with the Covent Garden Opera and various theatres.

James Thomson had planned a comprehensive educational tour. After six weeks in London the family travelled to Southampton and crossed the English Channel to Havre. The journey to Paris was made by steamer up the Seine, and the party of eight, including a very Scotch maid, attracted much attention.

William and his brothers were left in Paris, in charge of an old servant, to polish up their French; their father and their sisters, Elizabeth and Anna, journeyed by Napoleon's road over the Jura, resting at St. Laurent and Mores, and finally reaching Geneva. William Bottomley, an old pupil of James Thomson's in Belfast, arrived in Switzerland shortly after them, this was his first meeting with Anna, who was later to become his wife.*

* Their son, Dr. J. T. Bottomley, was one of the founder members of the present firm of Kelvin, Bottomley and Baird, Ltd.

The return journey was made through Lucerne, Zürich, Basle, Strasbourg, Baden-Baden, Karlsruhe, Heidelberg, Darmstadt, Frankfort and Paris. In Paris the party stayed for two weeks before leaving for London, where again it remained, this time for a week in lodgings near the British Museum, before the return to Glasgow towards the end of September, the whole tour having lasted some eighteen weeks.

In May, 1840, William secured his A.B. (Bachelor of Arts) degree when barely sixteen years old.* At this time, spurred on by their father, he and the others were studying German. James Thomson was so satisfied with the Continental tour of the previous year that he determined to make another educational journey, this time to Germany. The family remained together throughout the trip; at Bonn they were joined by Dr. J. P. Nichol, with his wife and son. Dr. Nichol was very good to the two boys, and acted as guide on many rambles, among them a three-days' tramp in the volcanic region of Sieben Gebirge. Coblenz, Mainz and Frankfort were visited.

Before setting out on this journey William had obtained from the College library a copy of Fourier's *Théorie Analytique de la Chaleur*. When studying the book one day he suddenly sprang up from the stool on which he was sitting, and exclaimed excitedly: 'Papa! Fourier is right and Kelland is wrong!' The father was at first incredulous, but on examination he found that William's contention was correct. He made William write for the *Cambridge Mathematical Journal* an article which was shown to Kelland before it was published. Kelland was at first annoyed; later he and William Thomson became firm friends. Although told by his father that he must study German when in Frankfort, William was more attracted to his Fourier, which he would read secretly in the trunk room. This book had a profound influence on his career.

In his last year as a student at Glasgow, William Thomson's thoughts were directed almost by chance to two subjects destined to engage his attention at times during the next sixty years. The first of these was the figure of the earth, the chosen subject for the Essay Prize, which he won. So thoroughly and comprehensively did he undertake this task that he often referred to this early essay in after-years to revive his memory of the

* He purposely refrained from accepting formal conferment of the degree, so as not to prejudice his entering Cambridge as an undergraduate.

subject; he even made a reference to it a few months before his death. The other subject was Fourier's Theorem, with which his first encounter can best be given in his own words:

'The origin of my devotion to these problems is that, after I had attended in 1839, Nichol's senior philosophy class, I had become filled with the utmost admiration for the splendour and poetry of Fourier. I asked Nichol if he thought I could read Fourier. He replied, "Perhaps". So on May 1, 1840, I took Fourier out of the University library and in a fortnight I had mastered it, gone right through it.'

In later life Lord Kelvin never abandoned his early intellectual interests, and when he had completed a piece of work that particularly pleased him he was always eager to proclaim that Fourier's Theorem was at the bottom of it.

William Thomson was barely seventeen when, on April 6, 1841, he entered St. Peter's College, Cambridge, as a student. This move entailed a great strain on James Thomson's financial resources; he had often to rebuke his son for extravagance—usually over the purchase of books with expensive calf bindings. But William was not averse to economy over less important things; he resisted the temptation to give his custom to a fashionable hairdresser at two shillings and sixpence a term, and proudly recorded in a letter home: 'I declined the tempting and advantageous offer, considering that my hairdressing has cost me 2*d.* the half year hitherto.'

The news soon spread that a freshman had arrived who had written a paper about Fourier's Theorem, a subject regarded at that time as so abstruse that there was doubt as to whether it should be included in the Mathematical Tripos examination. His mathematical prowess became widely known, and was a source of wonderment. He read mathematics with Hopkins, a great teacher, and wrote some mathematical papers. All this did not prevent him from finding relaxation. He was fond of the French horn, and became President of the Musical Society; he loved rowing, and won the Colquhoun Sculls.

University life gave him a wonderful chance to use his aptitude for friendship, and his chivalrous nature evoked strong affection in others. He chose his friends well, and they remained friends for life, many of them

attaining distinction of various kinds. One of them, recalling those student days sixty years afterwards, described William as 'a most engaging boy, brimful of fun and mischief, a high intellectual forehead, with fair curly hair and a beauty that was almost girlish'.

In June, 1844, a reading party was arranged and rooms taken at Cromer. The house was on the edge of the crumbling cliff, and must long since have collapsed. The money problem was still much to the fore, and the father wrote:

'In going to Cromer, or elsewhere, you must, of course, do as others do with regard to expense for lodgings, etc. You may have it in your power, however, consistently with propriety, directly or indirectly, to check extravagance in such things, and you ought to do so.'

To this admonition William replies:

'I have again to write you . . . to say that my money is again all gone. I spent nearly all the money you sent me in paying my Cambridge bills before I left, and the journey here, which was rather expensive, and my first week's expenses here have exhausted my stock so that I have only half a crown left. . . .'

During this educational holiday William became interested in problems which engaged his attention in after years. He wrote at the time: 'I have been investigating . . . the theory of spinning tops and rolling hoops, which is very curious and difficult.'

By the beginning of 1845, when the Mathematical Tripos examination was held, William Thomson was recognised as the ablest mathematician of his year, and there was tremendous excitement because on form and fitness it was expected that Thomson would win. But a 'dark horse' shattered the hopes of the family, and Thomson failed to become Senior Wrangler. He secured second place, the first prize going to a student who was quicker and more expert in 'writing out' the matter of the textbooks, and less concerned with the original problems which had proved too alluring to Thomson. Sir J. J. Thomson in his Centenary Oration summed up the position in these striking words: 'The honour this time fell to the fleet rather than to the strong.' A few weeks later Thomson was easily first in the examination for the Smith's Prizes, where speed of writing was not such a decisive factor.

William Thomson at the age of sixteen

(From a pencil drawing by his sister Elizabeth:
now in the National Portrait Gallery, London)

Quadrangle of the old Glasgow College

The rooms used as Laboratory of National Philosophy are in the dark corner on the right

After taking his degree Thomson spent two months in Paris working in Regnault's laboratory and becoming acquainted with the great French mathematicians Cauchy and Liouville. He now hoped for appointment to the Chair of Natural Philosophy at Glasgow, and sought to strengthen his claims by gaining experience in experimental physics. It is remarkable that in those few memorable weeks he received all his early training as a research worker.

This brief sojourn in Paris must unquestionably have given a great stimulus to Thomson; his future labours were deeply influenced by his study in Regnault's laboratory of Carnot's classic work on the motive power of heat. This work laid the foundation for the second law of thermodynamics, which Thomson did so much to develop. It had been published in 1824, the year in which Thomson was born.

THE TEACHER AND WRITER

On September 11, 1846, William Thomson, then only twenty-two years of age, was elected to the Chair of Natural Philosophy at Glasgow, which had become vacant by the death of Professor Meikleham, its occupant for forty-three years. Thomson held his Professorship for fifty-three years, so that together their tenures almost exactly bridged the nineteenth century.

There were many other candidates for the vacant chair, including the professors at Marischal College, Aberdeen, and Fredericton, New Brunswick, and a number of schoolmasters. But William Thomson and his father had set their hearts on his gaining of this high position. His application was supported by thirty testimonials, including those of W. Whewell, G. Stokes, H. V. Regnault and J. Liouville. James Thomson's joy in his son's success is revealed in a letter written at the time by the Rev. Dr. David King to his wife (William Thomson's sister Elizabeth) in which he said:

'The first announcement I had on the subject was your father's face as he came out of the hall where the election had been conducted. A coun-

tenance more expressive of delight was never witnessed. The emotion was so strong and marked, I only fear it may have done him injury.'

There was an ominous ring in this expression of a hidden fear. The fates decreed that the father should not live long to enjoy 'this great culmination of his happiness'. In 1848–49, Glasgow was plunged into mourning by a cholera epidemic which played havoc in the horrible slum district surrounding the old College. James Thomson caught the infection, and although the attack was not severe, he could not resist the aftermath of debility, and died on January 12, 1849. Fortunately, he had enjoyed the great satisfaction of welcoming his son as a colleague and witnessing the start of a brilliant career that had already begun to earn a European reputation.

At the start of his professorship Thomson had to overcome many difficulties, and later he wrote: 'When I entered upon the Professorship of Natural Philosophy at Glasgow there was absolutely no provision of any kind for experimental investigation, still less idea even for anything like students' practical work.'

In those first years he reorganised the teaching of Natural Philosophy, and improved the equipment so that lectures could be better illustrated by experiment, but he was hampered by the lack of experimental and accurate data upon which to base his theoretical investigations.

His experience in the Regnault laboratory in Paris had taught him the value and importance of accurate measurement of physical quantities; and he had witnessed such measurement undertaken by the patient, skilful hands of Joule. About 1850, an old disused wine-cellar in the College basement was converted into a laboratory, and there, under Thomson's guidance, the students experimented with the crudest equipment. Not until eighteen years later was the laboratory extended, by the annexation (without authority) of the abandoned Blackstone examination room.

This gloomy basement room was the first physical science laboratory established in Britain, and possibly in the world, which enabled students to do experimental work. Later on, when Thomson's practical bent led him into engineering and invention, the laboratory became an industrial research unit in embryo, the prototype of the modern research establishment essential to any progressive and efficient industrial enter-

prise. In this lair of scientific experimentation based on precise observation, accurate analysis, and sound deduction, Thomson began the application of science to the affairs of men.

His prolonged and arduous labours bridged the gap between the theoretical and the practical, between the secluded life of the university and the hard and baleful work-world of the nineteenth century, between education and industry. The future historian may well call this his greatest achievement; it becomes clear that the better world of which we dream must be worked out within the sphere of industry, in which so many people spend so much of their waking time. This working-out entails scientific approach and method, and the application of the principle—overlooked by Thomson and most others living in his era—that the overriding purpose of all endeavour must be the promotion of human well-being and happiness.

Measured by ordinary standards, Professor William Thomson was not outstanding as a lecturer and teacher. The violent impact of his original mind on a problem, and its often erratic movement through a vast range of subjects, was frequently a source of exasperation to his students. He would frequently stray from his main theme and proceed to 'think aloud'—a practice absorbing to himself, but a cause of impatience in his audience. But the power and attractiveness of his personality inspired his students with hero-worship; his success as a teacher resulted from his qualities of sincerity, humility, earnestness and kindliness.

One of his students wrote: 'Lord Kelvin's merit as an educator lies not so much in the elucidation of well-known facts as in the spiritual influence of his magnetic personality.' In this sense, he was a truly great teacher.

His abstruse dissertations often aroused expressions of impatience from his audiences. During a course of lectures on Magnetism he would frequently define an ideal magnet as 'an infinitely long, infinitely thin, uniform and uniformly, and longitudinally magnetised bar'. This pronouncement was usually accompanied by the sound of stamping feet from the back benches, which always drew forth a sharp 'Silence!' from the professor. This demonstration became so much a recognised part of the proceedings that on one occasion towards the close of a session, when through accident or design nobody stamped after the delivery of the

historic definition, Lord Kelvin by force of habit still finished his statement with a call of 'Silence!'

Those privileged to attend his lectures have recorded that often the most remarkable period would burst forth at the end 'like the brilliant stars of a rocket', just when the bell was beginning to ring for another lecture. Simple expressive phrases remained as jewels in the memories of his students. Once, when lecturing on the far-reaching influence of stresses and vibrations, he suddenly exclaimed: 'I lay this piece of chalk upon a granite mountain and it *strains the whole earth!*'

Throughout the years of his professorship Thomson would explain in his introductory lecture 'that Natural Philosophy has for its aim the observation and classification of the operations of nature, and the discovery of its laws by inductive generalisation based upon these observations'. For more than half a century he strove to enlarge our knowledge of nature and apply it to the service of mankind. His fertile and forceful mind roamed to good purpose through the interconnected realms of mathematics, mechanics, sound, light, heat, thermodynamics, magnetism, electricity, elasticity, telegraphy, electrical engineering, geology, astronomy, chemistry, and navigation.

The well-worn manuscript of that introductory lecture, written at the start of his professorship, did duty for over fifty years, although he did not rigidly adhere to it. Only twice, in 1871 and in 1880, was it read through to the end, with some deletions. The manuscript still exists, and the lecture was published for the first time in 1910.* Two paragraphs bearing a potent message for those now living are worth quotation. The first is as follows:

'Bacon places the delights of knowledge and learning above all other in nature. . . . He says: "We see in all other pleasures there is satiety, and after they be used their verdure departeth; which sheweth well they be but deceits of pleasure, and not pleasures; and that it was the novelty which pleased, not the quality. But of knowledge there is no satiety, but satisfaction and appetite are perpetually interchangeable; and therefore it appeareth to be good in itself simply without fallacy or accident".'

* *Life of William Thomson, Baron Kelvin of Largs*, by Professor S. P. Thompson. Vol. I, pp. 246, 247. (Macmillan & Co. Ltd., 1910).

And the second:

'The deep interest of scientific research cannot be entirely appreciated by those to whom such inquiries are strange; but it is felt in some degree by all who apply themselves in earnest to the study of Natural Philosophy. All of you, who are now commencing it, will I hope bestow enough time and thought upon the work to enable you to surmount the initial difficulties, such as necessarily occur when ideas of an entirely novel kind are brought before the mind. By sufficient perseverance, and by continual reference to the examples which you see in the world around you of the various physical actions and effects you will have to study, the habit of reasoning on the phenomena of nature will be acquired, and you will *then* begin to feel the enthusiasm which the subject inspires. Each one of you when he attempts the solution of a problem of difficulty, or struggles to comprehend a new principle, will have a share of that spirit of enterprise which led Newton on to his investigations; and when the problem is solved, when the doubts have vanished, a feeling of satisfaction will be the reward, similar to that which Newton himself must have felt after some of his great discoveries.'

In addition to his regular lectures and laboratory work, Thomson's written output was prodigious. A magnificent bibliography is to be found in the appendix to Volume II of S. P. Thompson's classic *Life*. An analysis of this bibliography shows that between May, 1841, and April, 1908—a period of sixty-seven years—he wrote 661 scientific communications and addresses; and between 1863 and 1909 he published twenty-five books. The rate of output of his scientific papers tended to rise with the passing of the years, as the following figures show:

1846	3
1847	10
1850	7
1854	12
1862	13
1884	15
1890	22
1896	10

In his writings Thomson developed a unique style, to convey his meaning. This point is illustrated in the title he chose for a paper read to the British Association in Edinburgh in 1892: 'The Reduction of every Problem of Two Freedoms in Conservative Dynamics to the Drawing of Geodetic Lines on a Surface of given Specific Curvature.' He invented the term 'mho', to denote the reciprocal of the 'ohm', the unit of resistance. In his writings are to be found such invented words as 'motivity', 'diffusivity', 'irrotational circulation', and 'infinitesimal satellites', and in consequence many of his books, such as the classic Thomson and Tait's *Natural Philosophy*, were nightmares for students of the period, who might find most of the subject-matter quite indigestible. Even in popular lectures and addresses he did not avoid this habit; but the spell of his personality established between himself and his audience a spiritual communion which profoundly influenced the latter.

The bewildering complexity of his writing and lectures was characteristic of the man; throughout his life he tackled every new problem by a method generally different from that of other people. As Sir J. J. Thomson said in his Centenary Oration:

'As his way of looking at things was different from that of most people it is not unnatural that he found it often difficult to understand the point of view of other writers, and that reading other people's work was not very congenial to him. He was an anomaly in physical science in that though he was a good radiator, he was a bad absorber. As this led him to think out almost everything for himself, I think it was an advantage in the progress of science. The mind is rarely so active when reading as it is in original thought, and I think he got a firmer grip of a subject by working it out for himself from the beginning, than he would if he had followed the lead, and perhaps acquired the bias, of some previous investigator.'

Lord Kelvin (in 1892 William Thomson had been raised to the peerage as Baron Kelvin of Largs) retired from the professorship in 1899, but continued to work as hard as ever. Lady Kelvin told Sir Edward Fry, who visited Lord Kelvin's home at Netherhall in the autumn of 1903, that after his resignation her husband 'felt no lack in his life, but went steadily on with his work as if no change had occurred'. Three years before his retirement Jubilee celebrations were held in the University; leading represen-

tatives of the scientific and educational world came from the four corners of the earth to do homage to a great man. Among the names of those present on that historic occasion was one destined to particular fame; the entry reads: *Princetown. Professor Woodrow Wilson.* Twenty years later, Professor Wilson was President of the United States of America, guiding his people towards participation in the first world war.

This chapter may fittingly be closed with words taken from the address presented to Kelvin by his beloved University:

'The fifty years during which you have occupied the Chair of Natural Philosophy in this University have to an extent unparalleled in the history of the world been marked by brilliant discoveries in every department of Physical Science, and by the prompt adaptation of many of these discoveries to meet the practical needs of mankind. We recognise with admiration that in both these respects you have been a leader of the age in which we live. Your mathematical and experimental genius have unveiled the secrets of nature; your marvellous gift of utilising such discoveries has ministered in many ways to the happiness and dignity of human life. Your name and your work have been an inspiration to the physicists of the world: new departments of technical industry have sprung into existence under your hand; and even the unlettered have learned to value the gifts which science bestows. The justice of the tributes which have been paid to you by Universities and Scientific Societies at home and abroad, and by the Governments of this and other lands, we are proud to acknowledge. But only your colleagues in University work are in a position to appreciate the versatility of faculty, the exhaustless energy, and the tenacity of purpose which have enabled you to grapple successfully with problems the most varied, and to reveal to us on every side the reign of order and law. In the midst of all, you have endeared yourself to us by the graces of your personal character, notably by that simplicity which, unmarred by honours or success, remains the permanent possession of transcendent genius, and by that humility of spirit which, the clearer the vision of truth becomes, bows with the lowlier reverence before the mystery of the universe.'

THE SCIENTIFIC INVESTIGATOR

Thomson's professorship provided the environment needed to give full scope to his peculiar genius. It has been pointed out that as a teacher he shone by reason of spiritual power rather than for his ability to impart knowledge to his students, but the beneficent influence of any teacher is always incalculable, for it may become a potent force in the lives of others. If it were possible to compile a true balance-sheet of human service, Thomson's work as a teacher might be found to transcend the more tangible and spectacular successes with which his name will always be associated.

Despite his arduous university duties, Thomson found time to pursue mathematical and scientific investigations, drawing continual inspiration from his teaching and experimental laboratory work. He maintained close contacts with leading scientific bodies, notably the British Association and the Royal Society in Edinburgh, and with other famous scientific investigators (such as James Prescott Joule, the young Manchester brewer, who at the early age of nineteen began his notable work on the mechanical equivalent of heat). And when in his early thirties, Thomson was impelled by his instinct for engineering towards that world of industry upon which his inventions were to exercise so powerful an effect.

In this short study it is possible to give only an outline picture of his tremendous achievements as a scientific investigator, engineer, and inventor. This work, at first glance lying outside the orbit of his professorship, gave added zest and fervour to his powers as a teacher.

But those achievements resulted in something of even greater importance. They forged a link between education and industry which strengthened the world of thought and the world of endeavour. We now see clearly that only by the strengthening of this link can we spread throughout industry a spirit of enlightenment in accord with Plato's vision of trade as a 'mother and nurse' serving mankind. And this vision must quickly become a reality if we are to achieve a better and happier world.

Thomson's life work, apart from teaching, falls into two main divisions

of investigation: (1) scientific and mathematical, and (2) engineering and industrial. The scientific and mathematical side may be subdivided as follows:

(*a*) *Thermodynamics*.—S. P. Thompson says * of Kelvin : 'If his work in Thermodynamics stood alone it would suffice to place his name as a natural philosopher beside that of Newton in its grasp of principles and generality of outlook.'

When in Regnault's laboratory in Paris in 1845, Thomson had studied Carnot's treatise on the motive power of heat. Carnot first conceived the idea of a reversible engine in which the working substance in a cylinder is made to actuate a piston through a cycle of temperature changes which involve the imparting of heat to the working substance from a hot source and the giving up of this heat to a refrigerator. Carnot's conception of the 'cycle', fundamental to the working of every heat engine, and his idea that reversibility was independent of the nature of the substance, were both sound. He assumed, quite incorrectly, that heat behaved like water and that the amount of heat taken from the source was equal to that given to the refrigerator. Actually, in accordance with the first law of thermodynamics, the work done during the cycle is: $W = H - h$, where $W =$ work done, $H =$ heat taken from source, $h =$ heat given to refrigerator.

It has already been stated that Carnot's treatise was published in 1824, the year Thomson was born; more than a generation passed before the science of thermodynamics was founded on enduring principles. Between 1850 and 1860 the second law of thermodynamics was established; and Thomson's contribution to that end was outstanding. Sir J. J. Thomson in his Centenary Oration said it had 'a good claim to be regarded as the most important of his many important contributions to physics'.

In this epoch-making work the name of James P. Joule will always be associated with that of Thomson. Joule, working alone in his Manchester laboratory, set out to determine the mechanical equivalent of heat by rotating a paddle wheel in a copper cylindrical vessel containing water, and measuring the rise of temperature corresponding to the work done. The motion of the paddle wheel was controlled by weights through a

* *Life of William Thomson, Baron Kelvin of Largs*, by Professor S. P. Thompson. Vol. I, Chap. VI.

system of pulleys and cords, and the distance through which the weights fell was measured on a scale.

Joule's first paper, read to the British Association in Cork in 1843, aroused little interest. In June, 1845, he read another paper 'On the Mechanical Equivalent of Heat' to the British Association meeting at Cambridge, once more without arousing enthusiasm for his theories. Undaunted, he brought the paper forward again at the Oxford meeting in 1847. Thomson was present at this meeting, and although the gathering was at first unsympathetic to Joule, Thomson's interest was aroused, and his observations stimulated a lively interest in the new theory. He made himself known to Joule after the meeting, and this first acquaintance, in his own words, 'ripened into a lifelong friendship'.

Joule had proved that work could be turned into heat, but Thomson at this time could not accept Joule's view of the equivalence of heat and work, and that heat could be turned into its equivalent of work. Thomson still held to Carnot's theory. An advance was made in 1850, when Clausius pointed out that the intrinsic worth of Carnot's principle was unaffected even if it were assumed that the heat given to the refrigerator is less than that taken from the boiler. This meant that the principle of the conservation of energy was not incompatible with the Carnot cycle, and immediately the chief impediment to the progress of thermodynamics was removed. In March, 1851, Thomson read his classic paper 'On the Dynamical Theory of Heat' to the Royal Society of Edinburgh; and this put matters in a new light and established the science of thermodynamics on an enduring basis.

(*b*) *Electric Oscillations.*—Despite his preoccupation with the science of thermodynamics, Thomson found time to delve into electrical problems. On January 19, 1853, he presented a classic paper to the Glasgow Philosophical Society under the title 'On Transient Electric Currents'. Following up a suggestion of von Helmholtz that an electric discharge from a Leyden jar or condenser might under certain conditions be oscillatory, Thomson worked out the conditions under which this would happen. Oscillation depends on the values of the resistance and the inductance of the circuit receiving the discharge, and the relationship they bear to the capacity of the condenser.

Thomson also deduced a formula for the frequency of the oscillations occurring under the first set of conditions. This was a great discovery, for in that phenomenon rests the origin of present-day wireless telegraphy and broadcasting; it is the basis of all methods of tuning now in vogue. Thomson's deduction stimulated many other workers in their search for electric waves; in 1859 Feddersen examined the spark discharge from a Leyden jar by means of a rotating mirror, and found that it exhibited definite fluctuations, indicating its oscillatory nature as predicted by Thomson.

In 1864 Clerk Maxwell promulgated the electromagnetic theory of light, which proved that a sunbeam was not made up of mechanical motions of the ether, as had been previously supposed, but that it consisted of electrical undulations. In 1888 Hertz succeeded in producing electromagnetic waves which he found had all the characteristics of waves of light, in that they travelled at the same speed, and could be reflected, refracted and polarised, thus proving Maxwell's theory to be correct. Thus was opened the door leading to wireless telegraphy and broadcasting.

Maxwell died in 1879; at that time Thomson's peculiarly individualistic outlook prevented him from accepting Maxwell's theory—which, nine years later, Hertz proved to be correct by a beautiful series of experiments based upon the use of oscillatory circuits designed in accordance with the principles laid down by Thomson in his paper of 1853.

(*c*) *Other Researches over a Wide and Heterogeneous Area.*—Space permits no more than a mention of Thomson's other investigations into a great variety of subjects, which included electrostatics, magnetism, the electrification of air, the dynamics of solids and liquids, the equilibrium and wave motion of elastic solids, the equilibrium of a gaseous envelope, the propagation of waves and ripples in water, vortex motion, the size of atoms, and the peculiar behaviour of crystals, to which he devoted a great deal of thought and attention in his closing years.

THE ENGINEER AND INVENTOR

Before Thomson was thirty years of age his practical engineering genius was turned towards the application of science to the needs of mankind. He pondered continually the possibilities of improvement in engineering design and construction; the experimental laboratory which he had established for his students, and especially its workshop, where his ideas could be quickly translated into models, were of great use to him in this direction.

The workshop was controlled by James White, who had succeeded the famous James Watt (of steam-engine renown) when Watt retired from the position of mathematical instrument maker to Glasgow University. Later, James White left the University to start business on his own account, and was then appointed philosophical instrument maker to the University. In token of this connection he mounted the University coat-of-arms above the door of his workshop in Renfield Street.

From the University, then, Thomson set out to replace ignorance, prejudice, and rule-of-thumb in industry by the application of scientific thinking and method. It has already been stated that perhaps the most enduring result of his exploratory labours is the bridging of the gap between education and industry; but his practical achievements profoundly influenced the growth of industrialisation during the nineteenth century, and still confer benefits upon those now living in all parts of the world. His remarkable services to industrial progress expressed themselves in three main directions: (1) the laying of the Atlantic cable; (2) his fundamental contribution to the art of precise measurement, and (3) his fundamental contribution to the art of navigation. Here it is possible to refer only briefly to each of these great undertakings.

1. THE LAYING OF THE ATLANTIC CABLE

The advent of the electric telegraph in 1837—the year in which the young Queen Victoria ascended the throne of England—marked the first big advance in long-distance communication.

The installation of land telegraphs was soon followed by that of submarine cables linking up countries and continents. In 1846 the first short submarine cable was laid in Portsmouth Harbour. This was followed by cables from Dover to Calais in 1850; from Holyhead to Howth in 1852; from Harwich to The Hague in 1853; and by a network of cables in the Mediterranean in 1855, including one to the Crimea, which was invaluable to the British War Office during the Crimea War.

It was soon found that the 'velocity of propagation' was reduced when an insulated cable was placed in water, owing to the 'capacity effect' associated with the name of Faraday, who first revealed its significance and importance. The copper conductor, and the water surrounding the cable, are in effect the two plates of an elongated condenser, with the dielectric between them in the form of the long annular tube of insulation surrounding the inner copper conductor. Thomson eagerly applied his mind to this problem, worked out a mathematical formula for the capacity of a cable, and communicated his work to Stokes in a letter written in 1854; in the following year he sent a communication to the Royal Society on the same subject. He showed that the electrical impulse at the sending end of the cable took time (T) to grow to maximum intensity, after which it gradually subsided. Thomson propounded 'The law of squares', which meant that the time (T) was proportional to the square of the length of the cable. With cables of equal length this time was directly proportional to both the resistance and capacity of the cable.

At this time Whitehouse, electrician to the Atlantic Telegraph Co., was preparing plans for laying a cable across the Atlantic. There was considerable controversy between Thomson and Whitehouse, who sought to dispute Thomson's theories. In December, 1856, Thomson was made a director of the Atlantic Telegraph Company, as the representative of the Scottish shareholders, and from that time onwards he energetically pursued the task of making this venture a success. He had to go cautiously, because the plan of operations—in Thomson's view a faulty plan—had already been decided upon. He first set himself to reduce both the resistance and capacity of the cable. By testing different samples of commercial copper he found in them an enormous variation in electrical conductivity. In some instances the copper content was only 50 per cent. He therefore

prepared specifications for the manufacturers, to ensure that conductivity would be maintained at a high and uniform level.

In August, 1857, the first attempt was made to lay a cable between Ireland and Newfoundland; Thomson was aboard one of the cable-laying ships, H.M.S. *Agamemnon.* Unfortunately the cable parted at 2,000 fathoms and the expedition returned to England. Thomson applied his mind to the design of a more sensitive detector; the result was the well-known mirror galvanometer, in which a light beam is reflected from the face of a small circular mirror to the back of which are attached tiny bar magnets. It is recorded that he conceived the idea of this revolutionary design, which is of fundamental importance to the whole science of electricity, by observing one day, when lecturing to his students, a spot of light jumping about erratically from wall to ceiling. Its beam, he found, was reflected from his eye-glass dangling in front of him at the end of a silken cord! He also improved the design of the transmitting keys, and in 1858 patented these inventions.

It was decided to make another attempt in that year, and at the request of his co-directors, Thomson became electrician on H.M.S. *Agamemnon.* In co-operation with the *Niagara,* a vessel loaned by the United States Government, the expedition successfully laid the cable to link Ireland and Newfoundland. On August 6, 1858, the first message was transmitted; and, as Thomson had anticipated, the older designs of instruments proved too insensitive. He substituted his mirror galvanometer, and messages were transmitted at the rate of two and a half words per minute. Unfortunately, as a result of faulty manufacture, the cable had a life of only two weeks; but in this short time 400 messages were transmitted across the Atlantic, and it was a good omen that the last word sent was 'forward'.

The next attempt was not made until 1865, when an accident led to the breakage of the cable; but at long last the determined efforts of these pioneers had its reward, and in July, 1866, the operation was successfully carried out from the cable-laying ship *Great Eastern.* The first message was passed on July 27. It is clear that Thomson's was an outstanding part in this far-reaching contribution to human progress.

The members of this final expedition of achievement were welcomed as heroes when they returned to Britain. Thomson and others of the party

were knighted; at a banquet given in their honour by the Lord Mayor of London, Thomson used words still worth repeating now that the boundaries of scientific knowledge have been extended far beyond his dreams.

'Unless men of science pursue their studies out of a pure love of knowledge or from an abstract desire to become acquainted with the laws of nature, they will seldom carry on their labours with success; but at the same time no greater reward could crown their investigations when, as in the case of Electric Telegraphy, they are the means of conferring a practical service on mankind, the value and importance of which are admitted on all hands. . . . *My only object in making these remarks is to point out that science, to be true to itself, must be followed for its own sake, and that all the most important services it has rendered to mankind have been the result of arduous investigations carried on by men animated with the hope of no other reward than that which awaits every sincere and industrious student of nature.*'

The italics are the present writer's.

The growing volume of business placed with the cable company made imperative an improvement in the signalling instruments; in 1867 Sir William Thomson invented his siphon recorder. He introduced a novel feature in the design of the instrument by fixing the magnet and allowing the coil to move—the basic principle underlying the design of present-day 'moving coil' instruments. The motion of the coil is communicated to a very fine capillary glass siphon, the shorter leg of which dips into a reservoir of ink, while the larger limb acts as a pen. The paper is a tape, moved by clockwork over a brass table and underneath the pen, but not touching it. The ink is electrified by a small clockwork-driven induction machine, and in consequence of vibration imparted mechanically to the siphon, minute drops of ink are shot on to the moving paper strip. Thus the message, in the form of a wavy line, is automatically recorded on the moving paper.

2. FUNDAMENTAL CONTRIBUTION TO THE ART OF PRECISE MEASUREMENT

The influence Kelvin brought to bear on the development of the electrical art was profound. Especially is this true of his fundamental contribution to the art of precise measurement. Most of his early papers on the subject of electricity were on electrostatics, and in 1845, when only

twenty-one years old, he contributed two papers to the *Louiville Mathematical Journal*. In one of these papers he discussed the experiments of Sir William Snow Harris, for which the Copley Gold Medal of the Royal Society had been awarded. Thomson showed that these experiments, which were thought to be at variance with Coulomb's Laws, really confirmed them when the conditions under which the experiments were made were fully considered. In this paper he made a first attempt to establish a mathematical theory of electricity, based on Faraday's discovery of electro-magnetic induction in 1831.

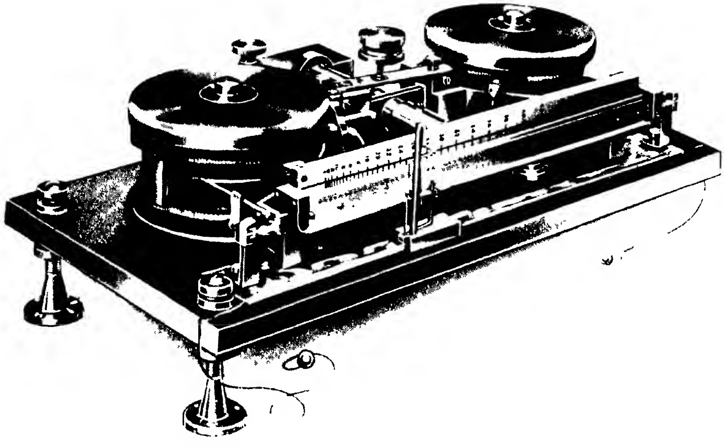
At this time progress in electrical investigation was greatly hampered for two fundamental reasons: (1) the purely arbitrary system of electric units adopted by experimenters (in other words, there was no common measuring-stick); and (2) the crudeness and insensitivity of the measuring instruments available. Thomson set out to remove these handicaps, and in later years was so successful that he laid an enduring foundation for the spectacular development of the past half-century.

(*a*) *Founding of System of Units*.—J. K. F. Gauss had already propounded the absolute system of dynamical and magnetical units, and in 1851 W. E. Weber extended it to electromagnetism. Thomson hailed Weber's work with enthusiasm, and in the same year prepared a paper on 'Applications of the Principle of Mechanical Effect to the Measurement of Electromotive Forces, and of Galvanic Resistances in Absolute Units'.

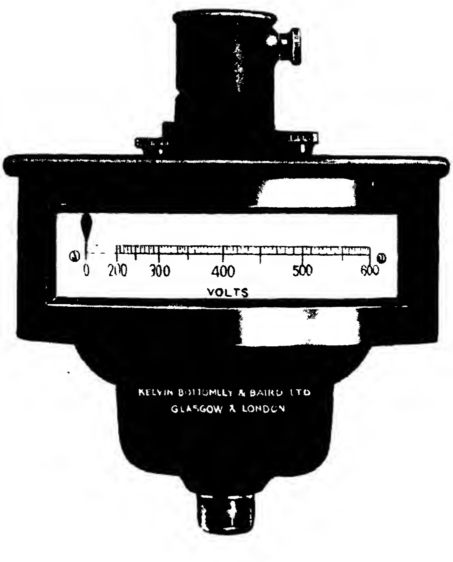
Weber's unit of electromotive force was derived from Faraday's principle of electromagnetic induction. Thomson introduced the idea of mechanical effect and showed that 'if a current of uniform strength be sustained in a linear conductor, and if an electromotive force act in this conductor in the same direction as the current, it will produce work at a rate equal to the number measuring the force multiplied by the number measuring the strength of the current'.

In this paper, for the first time, the electromotive force of a Daniell cell is calculated in absolute units, and the ingenious method of measuring the absolute resistance of a wire by determining the heat generated by the passage of a known current through it is disclosed—the beginning of absolute electrical measurement.

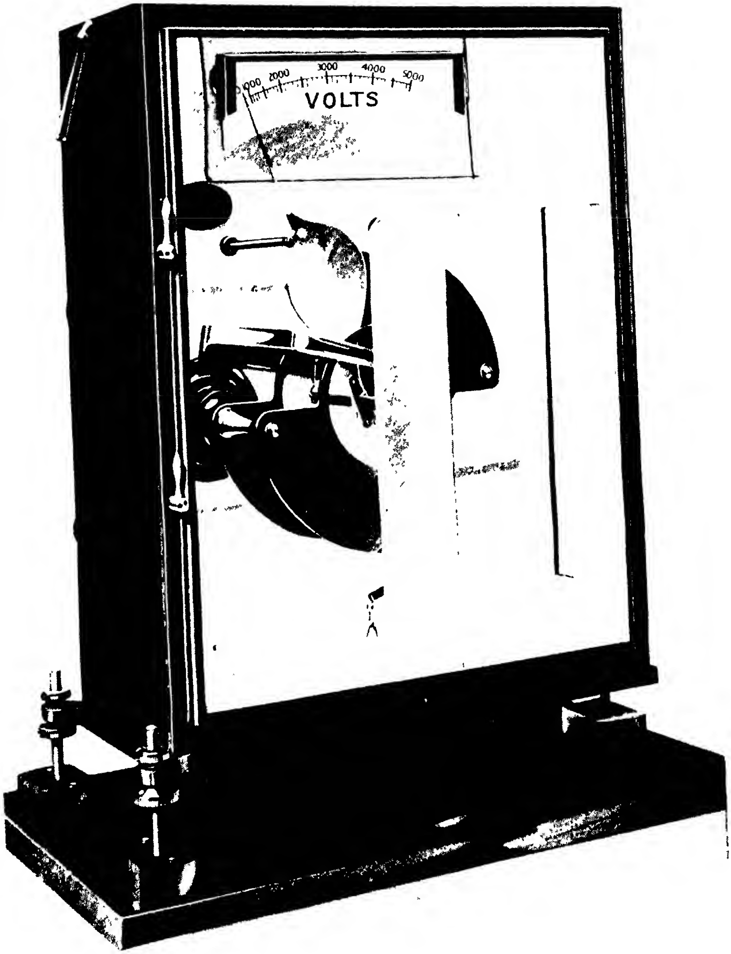
Thomson was an enthusiastic protagonist of the absolute system, both



Kelvin Ampère Balance



Kelvin Multicellular Electrostatic Voltmeter



Kelvin Vertical Electrostatic Voltmeter

for investigational work and also for telegraphy, which at that time was the only important practical application of electricity. Largely through his efforts, the British Association set up in 1861 a committee on electrical standards. He was an outstanding and determined member of this committee, which during the next ten years accomplished fundamental work, facilitating progress in the harnessing of electricity to the service of mankind.

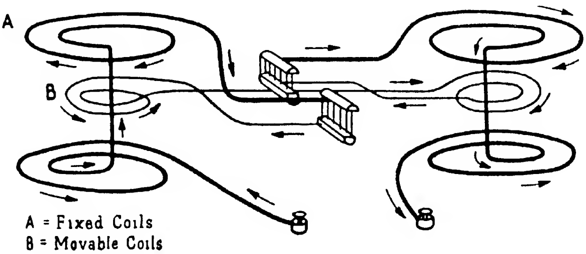
(*b*) *The Perfecting of Precision Measuring Instruments.*—The adoption of absolute units marked an important advance, but its value could only be exploited when the necessary instruments were made available. Thomson applied his mind to the problem; many of the instruments he designed are still in daily use. This, again, in a hundred years' time may be regarded as his greatest achievement.

Human progress, whether in the realms of the tangible or the intangible, is dependent on skill and ability to measure accurately, at any point of time, those factors which influence the course of that progress. This fact has for long been fairly obvious as regards material things, but the shape of things to come will also be influenced by the application of this principle of measurement to things hitherto assumed to lie outside the scope of measurement. Hence the vital importance of research in the relatively new field of social science. In recent times we have witnessed the advent of the Gallup Poll, a system of measurement applied to democratic groups to ascertain their reactions to current problems; and great advances have been made, especially through work in the Armed Forces during the war years, in the furthering and perfecting of so-called psychological tests valuable in the process of education and in the fitting of the individual into his proper niche in the world of work.

Thomson perhaps foresaw this extension of principle when, nearly a hundred years ago, he wrote the following pregnant passage:

'I often say that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it in numbers your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science whatever the matter may be.'

(*c*) *Electrical Measuring Instruments.*—As early as 1845 Thomson applied his mind to the evolution of two fundamental types of instrument for measurement of static and dynamic electrical forces—the first the electrometer, and the second the electrodynamic balance based on Ampère's law governing the forces set up between parallel conductors carrying electric current (see diagram). The instruments which resulted from his work can be grouped as follows: (1) portable, absolute and quadrant electrometers; (2) the delicate mirror galvanometer; (3) graded galvanometers, voltmeters and balances designed for commercial use.



Principle of the Kelvin Current Balance

In 1853 Thomson showed the possibility of construction of an instrument to measure electrostatic potential in absolute units. Two years later he exhibited his absolute electrometer to the British Association. In 1860 he used this instrument in the course of a research to determine the electric pressure required to produce a spark in the air, and absolute electrostatic measurements were then made for the first time. The instrument is very simple, consisting of two insulated circular brass plates, one fixed, the other adapted for movement towards or away from the fixed plate through an ascertainable distance. The fixed plate has a circular hole at its centre in which is suspended a small aluminium disc.

In use, the fixed plate, with its suspended disc, are charged by a frictional machine and the movable plate then adjusted to bring the floating aluminium disc to its normal position in the centre of the fixed plate. The movable plate is then connected to the source of supply whose

potential has to be measured, and the distance between it and the fixed plate is varied until the aluminium disc again assumes its normal position. The applied potential is calculated in absolute units from the distance through which the fixed plate is moved, the force exerted by the mechanism (springs and counterpoise) controlling the aluminium disc, and the area of the disc itself.

This same principle of measuring the force of attraction of a disc was used in his long-range electrometer for measuring potentials from 4,000 to 80,000 volts, and also in a portable electrometer. In the *Transactions of the Pontifical Academy of Rome* for 1857 there appears a description of Lord Kelvin's first divided ring electrometer. This later evolved into the well-known Thomson quadrant electrometer, from which were developed the multicellular electrostatic voltmeter and the vertical electrostatic voltmeter, (see illustrations facing pages 26 and 27), two instruments which have proved invaluable to research laboratories all over the world, and are still to be found in every up-to-date electrical testing establishment.

3. FUNDAMENTAL CONTRIBUTION TO THE ART OF NAVIGATION

In 1870, after the death of his first wife, Sir William Thomson, as he then was, sought a measure of consolation from his love of the sea. He purchased the *Lalla Rookh*, a large sailing yacht of 126 tons, and spent much of his spare time cruising to distant places. Parties of friends frequently accompanied him, including on one occasion von Helmholtz and his wife. Thomson's work in connection with the laying of the Atlantic cable had introduced him to seafaring men, and aroused his interest in navigational problems. The *Lalla Rookh*, indeed, became a kind of floating research laboratory. Foremost among his enduring contributions to the art of navigation was his improvement of the magnetic compass; he also invented a most ingenious sounding-device comprising an inverted tube, closed at one end, and coated on the inside with silver chromate. When this tube was lowered into the water the air was compressed and the depth could be deduced from the height of the water-mark inside the tube as measured by the remaining film of silver chromate. Thomson also improved the method of sounding by attaching the

sinker to a thin piano-wire, which offered such small resistance to the water that measurements could be made while the ship was in motion. The older method, by which a thick hemp rope was attached to the sinker, had necessitated the stopping of the ship.

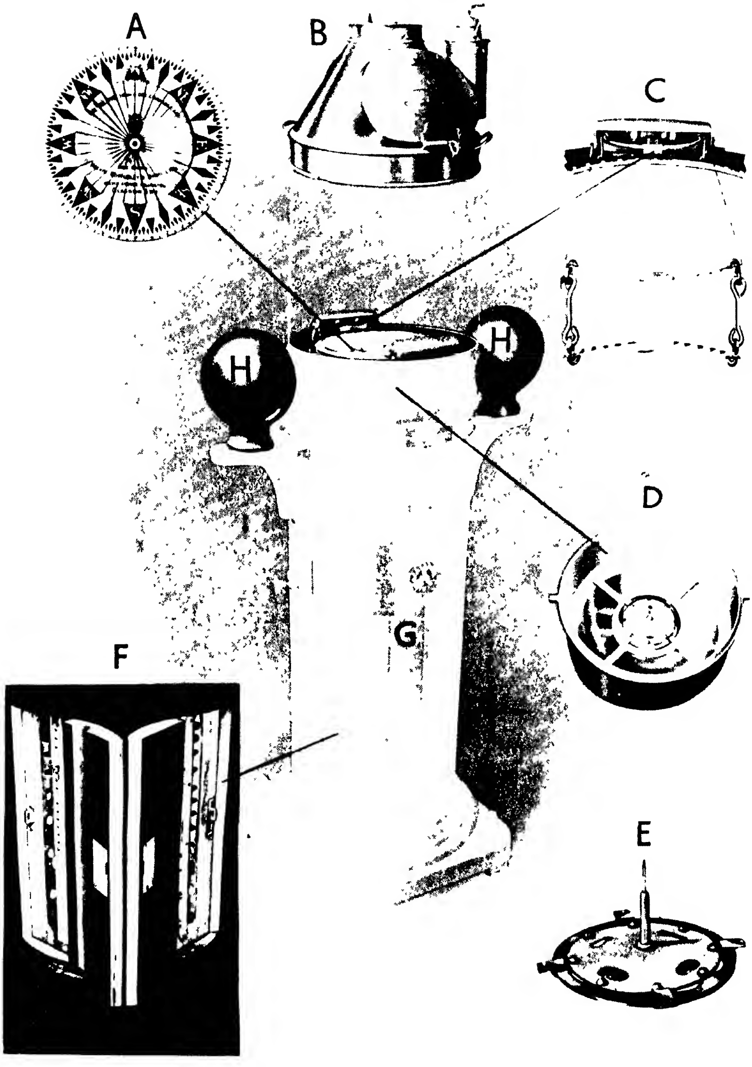
The story of how he was led to improve the magnetic compass is worth telling. He was asked to write a series of articles on the Mariner's Compass for *Good Words*, and the first of these appeared in 1874; the second was not forthcoming until five years later! Before writing the first article he had studied existing designs, and perceived their fundamental weaknesses, especially the error due to the magnetism of the ship. He set out to repair these weaknesses; and in the five years' period between his first and second *Good Words* articles he perfected the Magnetic Compass, still used to-day in substantially the same form on ships on all the seas of the world. Once again he had made a contribution to science which may in the future be considered his chief title to fame.

Sir William Thomson referred to this episode in one of his published lectures at that time in these words: 'When there seemed a possibility of finding a compass which should fulfil the conditions of the problem, I felt it impossible to complacently describe compasses which fulfil their duty ill, or less well than might be, through not fulfilling these conditions.'

The fundamental improvements worked into his design were: (*a*) reduction of the weight of the moving card by attaching to it a series of fine parallel needles which acted as magnets; and (*b*) compensation for the magnetism of the ship by the provision of magnets and masses of soft iron at or near the binnacle, following the method that had been published in 1837 by Sir George Biddell Airy, Astronomer Royal from 1835 to 1881.

At all periods of the world's history there have been individuals who decry any progressive idea, saying 'it can't possibly work'. This was said of the telephone, invented by Graham Bell just at the time when Thomson produced his improved compass, and of the phonograph of Edison. Thomson's own work did not escape manifestations of this reactionary attitude.

Mr. J. Munro has recorded that Thomson asked him one day to show



Kelvin's Mariner's Compass

This is the modern form as now manufactured by Messrs. Kelvin Bottomley and Baird Ltd. in their Glasgow works The displayed components are: (A) ten-inch compass card; (B) binnacle helmet; (C) anti-vibration suspension, (D) interior of bowl; (E) four-pivot anti-vibration support on which compass card rotates, (F) view of corrector magnet housing, (G) binnacle body; (H) spherical soft iron correctors.

Lord Kelvin with one of his 'green books', discussing a problem with his sister Elizabeth (the artist, Mrs. Thomson King)

(From a photograph by Agnes Gardner King)

one of the new compasses to Sir George Airy at the Royal Observatory, Greenwich Park, and obtain his opinion of it. Although the model was crude, it contained all the essential improvements; Sir George examined it thoughtfully for some time, and said: 'It won't do.' When Sir William Thomson was told of this verdict his only comment, which showed no bitterness, was: 'So much for the Astronomer Royal's opinion.'

While awaiting the final blessing of the Admiralty on his improved compass, Thomson found time to advocate the system of flashing lighthouse beams, and to invent a tide gauge and a tide predicting machine, both of which are still manufactured substantially in the form designed by him.

4. INDUSTRIAL ENTERPRISE: KELVIN, BOTTOMLEY AND BAIRD, LTD.

Thomson's happy association with James White in his early university days was strengthened with the passing of years. It was a unique combination; White's sensitive craftsmanship ably seconded the scientific engineering genius of Thomson. During the eighteenfifties, when Thomson was engaged with problems connected with the laying of the Atlantic cable, White's business began to grow by the addition of submarine and nautical departments. Much later, in 1883, White took in two partners, and the business was moved to a larger factory site in Cambridge Street.

The following year White died, and in 1890 his two partners retired. Sir William Thomson, with his nephew Dr. J. T. Bottomley, took a financial interest in the business and enlarged the premises. The factory was thoroughly modernised, and fitted with electric lighting; this was the first factory installation of electric light in Scotland. In 1892, as already stated, Thomson was created Lord Kelvin; in 1900 the business became a private limited company under the name of Kelvin and James White, Ltd.—a mark of loyalty to Kelvin's old friend and colleague.

Following the death of Kelvin in 1907, Dr. Bottomley succeeded him as chairman. Years before, a young man named Baird had been trained by Thomson to adjust his compasses, and had grown up with the business. Early in the present century the manufacture of compasses had become a most important part of the company's activities; in 1913 Mr. Baird was

invited to join the Board, and the name of the firm was changed to Kelvin, Bottomley and Baird, Ltd., as it remains to-day.

In recent years the company has expanded considerably. In anticipation of the demand that would arise for new types of instruments for aircraft, a new factory was erected at Basingstoke in 1936; in 1940 manufacture in Glasgow was moved from Cambridge Street to new buildings at Hillington on the outskirts of the city.

THE MAN

Kelvin's contemporaries must have regarded him as a fortunate man. His inventions, covered by no less than seventy patents, and his many directorships brought him considerable wealth and social prestige. After his death his fortune was valued at £161,923. He was twice married, first in 1852 to Margaret Crum, a cultured and beautiful but delicate woman; she became ill after their honeymoon in Sicily, the strain of travelling and sightseeing having been too much for her frail constitution. She was more or less a permanent invalid for eighteen years, and died in 1870. In 1874 Sir William Thomson married Miss Frances Blandy, daughter of a prominent landowner on the island of Madeira, which he had visited the previous year in connection with the laying of a South American cable. It was a happy union, and his new wife became a most capable hostess and manager of the new home which was built for her at Largs. It was a large country house called Netherhall, and fitted with all kinds of engineering devices and amenities. In 1881 electric lighting was installed; Netherhall must have been one of the first homes in the country to be so provided.

Both marriages were childless; and a psychological study of this great man might reveal some connection between the absence of children from his own fireside and astonishing creative energy displayed throughout his long life. He was actually engaged on completing a paper on his deathbed; it was published by his secretary after his death. This extraordinary capacity for continuous mental activity was one of Kelvin's outstanding characteristics. Even when his home was full of nieces and friends, he still continued working in their presence, with the current 'little green book' on his knee; indeed, in some mysterious way he derived a stimulus from

their company and activities. By no means completely lost in contemplation as might have been supposed, he would often interject a remark proving that he was fully alive to what was going on around him.

This machine-like intensity and precision of mental labour and physical habits must have prevented him from enjoying to the full social activities of any kind. He seems not to have acquired the art of completely abandoning work, even for a short spell. Henry Ford once said that the proper blending of work and play is one of the most important things to be learnt in mastering the art of living; it must be concluded that Kelvin somehow failed to achieve this combination. This fact helps to explain why he was not a good absorber of the thoughts and feelings of others. This individualistic trait, fostered by an early environment dominated by a loving and purposeful father, possibly prevented that closer collaboration with Faraday which, it has been suggested, might have had far-reaching consequences.

The two great men met for the first time in 1845, after a meeting of the British Association at which Thomson had read a paper in which he sought to give mathematical expression to Faraday's imaginary lines of force. Subsequently, Thomson wrote to Faraday proposing to meet him at the Royal Institution, but Faraday was leaving London and this first contact did not immediately ripen. J. G. Crowther,* writing of this incident, says:

'This early contact with Faraday is one of the most dramatic incidents in Thomson's career. It shows at once his tremendous powers and the limitations of Faraday himself. The youth had foreseen the Röntgen dielectric hysteresis effect and the Kerr effect, he had started the discovery of the mathematical expressions of Faraday's conceptions, but through the detachment that was one of his deepest characteristics he had not read Faraday's works thoroughly; though he had the highest regard for Faraday he was unable to establish a communication of intellectual feeling with him. Perhaps Faraday's departure from London was the unfortunate cause. The results of a thorough combination of Faraday's intellectual feeling with Thomson's mathematical power and insight would have

* *William Thomson*, by J. G Crowther. Essay in *British Scientists of the Nineteenth Century* Vol. II. (Pelican Books).

heaved human culture. The imperfect combination that was established proved sufficient to fire Maxwell's imagination.'

Faraday, like Kelvin, was childless. But temperamentally the two men were cast in different moulds; the present writer inclines to the view that they could hardly have worked together as a team. This fundamental difference is revealed by the manner in which they responded to the opportunity to engage in commercial and lucrative activities. Faraday, when forty years of age, immediately following his epoch-making discovery of electromagnetic induction, resisted the attraction of wealth and social position; he found complete happiness in his laboratory on £5 per week, and died a poor man. William Thomson, when about thirty, encountered the same problem. Following a natural inclination, he entered the industrial sphere and became in later life a Director of the Newcastle Electric Supply Company, the British Aluminium Company, and the Kodak Company in addition to directing the firm of Kelvin and White.

Despite this temperamental difference, Kelvin had an abiding admiration and affection for Faraday. His niece has written: *

'The dominant characteristic of Lord Kelvin was his extreme lovableness which seemed to grow and broaden with advancing years. He had a certain fieriness of character which was quickly roused to indignation by any meanness, or even by inaccuracy or foolish conceit, and which then burst forth in no measured tones. This became merged as time went on in the greatness of his gentler nature, which grew too full of love for God and man to leave much room for other feelings.'

These high qualities are beautifully exemplified in his tribute to Faraday, paid after the latter's death in 1867. Opening the mathematics and physics section of the meeting of the British Association in that year, Kelvin—then, of course, still Sir William Thomson—said:

'I wish I could put in words something of the image which the name of Faraday always suggests to my mind. Kindliness and unselfishness of disposition; clearness and singleness of purpose; brevity, simplicity and directness; sympathy, with his audience or his friend; perfect natural tact and good taste; thorough cultivation—all these he had, each in a rare degree; and their influence pervaded his language and manner whether in

* *Kelvin the Man*, by Agnes Gardner King. (Hodder and Stoughton, Ltd., 1925.)

conversation or in lecture. . . . Something of the light of his genius irradiated his presence with a certain bright intelligence, and gave a singular charm to his manner which was felt by everyone, surely, from the deepest philosopher to the simplest child.'

Honours were showered upon Thomson in later life. He received honorary degrees from the Universities of Cambridge, Oxford and Heidelberg; he became President of many learned societies, including the Royal Society of Edinburgh, the British Association, and the Institution of Electrical Engineers. In 1890 he was elected to the Presidency of the Royal Society of London, which since the time of Newton has been the highest professional honour to which a British man of science can aspire. In 1892 his peerage was conferred upon him by Queen Victoria. Four years later came the jubilee celebration of his professorship, which was held in Glasgow University on June 15, 16 and 17, 1896. It was attended by some 2,500 representatives of universities, societies and institutions, and by other distinguished visitors from this country and overseas. That part of Kelvin's speech made on this great occasion, in which he used the word 'failure' to describe his life's work, has been much quoted. It symbolises the selfless faith and simplicity of purpose which mark true greatness. He said:

'One word characterises the most strenuous of the efforts for the advancement of science that I have made perseveringly during fifty-five years; that word is FAILURE. I know no more of electric and magnetic force, or of the relation between ether, electricity, and ponderable matter, or of chemical affinity, than I knew and tried to teach to my students of Natural Philosophy fifty years ago in my first session as Professor. Something of sadness must come of failure; but in the pursuit of science, inborn necessity to make the effort brings with it much of the *certaminis gaudia* and saves the naturalist from being wholly miserable, perhaps even allows him to be fairly happy in his daily work.'

In 1902 Kelvin was made a member of the Privy Council. In the same year he had the distinction of being one of the first recipients of the new Order of Merit (O.M.). But the floodtide of honours had no effect upon his way of life; in his latest years there was little change in the range and intensity of his work.

The end came peacefully at Netherhall on the evening of December 17, 1907, in the presence of his physician, three of his nephews, two nieces-in-law, and several faithful servants. Lady Kelvin was ill at the time in an adjoining room; anxiety over her illness had hastened his end. Lord Kelvin was buried in Westminster Abbey in a tomb adjoining that of Sir Isaac Newton.

HIS WORK: AN APPRAISAL

Lord Kelvin was a famous figure of the nineteenth century; and his vision and prowess were profoundly influenced by the spirit of the age in which he lived—the Victorian era, characterised by the growth of machine-power, when Britain led the world in industrial development. It is now evident that one of the inherent weaknesses of that era was that the leaders of mechanical progress confined their thinking by the boundaries of the mechanical, and discarded—except perhaps on Sundays—any reference to intangible realities.

The power to rise above one's environment and search the clouds which conceal ultimate truth may be vouchsafed only to a small number of exceptionally gifted minds in any age; that small number must be considered the truly great men. It is no reflection on Kelvin's enormous contribution to the progress of applied science to say that in this respect he does not seem to attain to the greatness of Michael Faraday and Clerk Maxwell. This point cannot be better illustrated than by the fundamental change that has come over astronomical thought during the present century, a change beautifully described by the late Sir James Jeans when he said that we have now moved away from the earlier conception of the universe as being a vast machine working with mathematical precision, to the finer view that 'it begins to look more like a great thought than a great machine'.

The spectacular advent, in the middle twentieth century, of the electronic age continues that movement, despite the extraordinary skill and perfect precision with which electrons can be counted, manipulated, and controlled to serve human needs. No one has ever seen an electron, and we know no more about the fundamental nature of electricity than was

vouchsafed to Thales 2,600 years ago. We do know, however, that it is a power permeating all animate and inanimate things; that it is akin to spirit; that it draws us close to the eternal mystery of nature and sets us face to face with God, the Ruler and Planner of all.

The writer asked Professor H. T. H. Piaggio, of University College, Nottingham, with whom he spent many happy days as a schoolboy, to give his interpretation of Lord Kelvin's position with respect to the revolutionary conceptions of present-day mathematical and scientific teams. Professor Piaggio's statement, quoted below, not only gives a valuable picture of the revolution in physical science that has occurred since the death of Kelvin in 1907, but also provides a background for a true appraisal of Kelvin's life-work.

'To understand fully the enormous reputation enjoyed by Lord Kelvin in the nineteenth century, a reputation due to the perfect accord with the spirit of that age of his strange combination of genius and prejudice, we must consider the change in physical ideas since 1900. The change is so great as to amount to a revolution. No generalisation seemed better founded than that of Linnaeus, "Nature does not make jumps". Yet the experimental facts concerning the radiation of heat forced Planck to abandon this assumption of continuity. In 1900 he put forward the amazing hypothesis that the emission of energy took place in discontinuous jumps, of amount equal to the product of the frequency and of an extremely small constant, now known as Planck's constant. In 1905 Einstein showed that the same law applied to the emission of light. In 1913 Bohr made the first successful attempt to explain the long-standing puzzle of the bright lines seen when the light emitted by the passage of electricity through hydrogen is examined with a spectroscope. His explanation was based on a union of Rutherford's ideas on the constitution of the atom (ideas flatly rejected by Kelvin as late as 1907) and Planck's quantum hypothesis. This explanation worked well for the hydrogen atom, and was with some difficulty extended to certain other elements. But the work was like pouring new wine into old bottles, for it was an illogical combination of the new quantum theories and the old classical theories which were really incompatible with each other.

'The next stage of development, the complete emancipation of quantum

mechanics from classical physics, was delayed for some time. When it did come, in 1925–26, it was reached independently in several different ways, by Louis de Broglie, Schrödinger, Heisenberg (in conjunction with Born and Jordan), and by P. A. M. Dirac (probably the greatest living British mathematical physicist). They were guided by a marvellous combination of physical instinct and mathematical technique; using not only the recent mathematics of Hilbert and Courant, but also the dynamics of Sir William Rowan Hamilton, which was too far in advance of its age to be fully appreciated in the nineteenth century.

'Only one thing was lacking, and that was logic. The arguments were really unsound, but nevertheless the conclusions reached proved to be a firm basis for accurate prediction, later supported by an ever-increasing number of experiments. Perhaps the most striking of these experiments were those initiated by Sir George Thomson on the transmission of a beam of electrons by a very thin metallic film, which is really a random arrangement of very tiny crystals. The scattered electrons formed sets of concentric rings just like those formed by the diffraction of waves of light, or of X-rays by powders.

'For this reason the new theory may be called Wave Mechanics. In the form that is simplest to use, we start with a certain partial differential equation called Schrödinger's equation. At first there was considerable doubt as to the physical meaning of the mathematical function satisfying this equation, but later Born showed that it was related to the probability of the occurrence of an electron in any given position. The surprising thing is that this equation, obtained in the most unconvincing manner, nevertheless seems to contain in itself (or rather with the addition of a few simple and plausible general postulates) the basis of nearly all physical truth. By the application of purely mathematical processes we can deduce the quantum jumps, wave-lengths, and intensity of the bright lines seen in the spectroscope. The method has been extended from atoms to molecules and chemical compounds and the modern chemist uses quantum mechanics for the explanation of valency. Other applications are to metallurgy, magnetism, and even philosophy.

'The suggested applications to biology (explaining mutations as quantum jumps) and to religion may or may not be valid. There is no doubt as to the

legitimacy of the deduction, from the basic principles of quantum mechanics, of Heisenberg's Principle of Uncertainty. This shows that it is impossible to measure with perfect accuracy, at the same time, the position and velocity of an electron. What is in doubt is how far this principle leads us. Does it, as von Neumann asserts, constitute a definite disproof of the least doubted of all physical laws, that of cause and effect? Still more doubtful, does it, as Sir Arthur Eddington and others have conjectured, throw any light on the problem of human freewill?

'We can imagine with what vehemence Kelvin would have rejected all this. No theory would satisfy him unless he could imagine a model of it. . . . We cannot escape the conclusion that Kelvin's mind, so splendidly successful in dealing with thermodynamics, the science of the steam engine, and with all that pertained to the theory and practice of electrical engineering (with the exception of radio), yet was so prejudiced in favour of engineering concepts that he was unable to accept any developments not conceivable in such a way. . . .

'We cannot blame Kelvin for not knowing what no one had yet discovered, but it is regrettable that he was so dogmatic in contradicting the geologists about the age of the earth. The geological and physical arguments gave widely different results, but Strutt showed later that it was Kelvin's argument, based on the rate of cooling of the earth, that was unsound. The dominant fact, then unknown, was that heat was derived from the radioactivity of certain rocks. It is surprising that Kelvin did not later on, think of this possibility, as he had been one of the first to encourage the work of Madame and M. Curie. Kelvin also calculated the period during which the sun has illumined the earth, but Eddington has shown that it is at least extremely probable that the basis of the calculation is entirely unsound, and that the dominant fact is the peculiar state of the atoms comprising the sun's substance.

'The laws of the world of the astronomically great, unlike those of the sub-atomically small, are almost entirely due to one man, Albert Einstein. As is well known from the lucid explanations of Sir Arthur Eddington, the discrepancy between the observed and calculated positions of the planet Mercury makes it necessary to discard, except as excellent approximations, Newton's laws of motion and gravitation. This general or gravita-

tional theory of relativity appeared in 1915, but owing to the war was little known in England until 1919, when Eddington's verification of Einstein's prediction concerning the apparent radial displacement of the stars near the sun during an eclipse arrested general attention.

'The earlier form of the theory, restricted to uniform relative velocity, appeared in 1905, two years before Kelvin's death, but there is no evidence that he was interested in it. Yet the Michelson and Morley experiment, on which the theory is based, was performed as early as 1881–87, and was referred to in Kelvin's Baltimore Lectures as "one of the clouds on the wave-theory of light". It is not surprising that he never thought of abandoning the traditional ideas of constant mass, absolute space, and absolute time.

'To sum up, Kelvin's genius was supreme on the lines to which his prejudices limited him. Both genius and limitations were those of the great engineer, and both were admired by his contemporaries. Kelvin went as far as anyone could along classical lines. The fact that, in his own words (1896) the result was "failure" (in the sense that he had not been able to derive a mechanical model to explain optics, electricity, and magnetism), served as a warning to later workers to proceed along different lines, and thus may have helped to produce the enormous increase of knowledge in the present century. But we must not repeat his mistake in thinking that our present ideas are necessarily absolutely true or final. Those who know most about them are fully conscious of their weaknesses. Even if no such weaknesses were known, all that we should be entitled to assert is that the observed facts, so far recorded, agree with the predictions made on the basis of Schrödinger's equation and similar *postulates*. The consequences are *as if* these postulates were true. If new results are found which do not agree with the predictions, we must revise our postulates. Meanwhile, for ordinary purposes, Newton's principles are such excellent approximations that they are the first we think of using, but not necessarily the last.'

Kelvin's fame is likely to endure because of his achievements in three main directions:

(1) His great contribution to the science of thermodynamics.

(2) The foundation he laid so well for the science and art of precise

measurement; a function fundamental to wholesome life and progress in this mechanistic age.

(3) His fervent proclamation by precept and example of the importance of the scientific outlook within the world of industry. Especially notable were his founding at Glasgow University of what was in fact the prototype of the modern industrial research establishment, and the bridging, by his life's work, of that ominous gulf between education and industry which must be filled by a unity of intercourse and purpose if we are to secure—as we must—the rapid spread of those humanising and enlightening forces within the world of industry upon which the future well-being of all peoples so largely depends.

This chapter and this study cannot be better closed than by quotation with enthusiastic approval of the concluding paragraph of the Kelvin Centenary Oration delivered by Sir J. J. Thomson in 1924, when he said:

'We are commemorating to-day the memory of one to whom British science owes much of its prestige, who by methods all his own made vast and important additions to our knowledge, who is the outstanding figure in the union of theory and practice, and who has left us an example of unremitting, untiring devotion to a great ideal.'